DO-IT: Decision Analysis for Technology Investment

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Methodology

- **Select advanced future mission(s) options**
- **Characterize and quantify science goals**
- **Articulate success criteria for study (e.g. highest probability of success for fixed cost; minimal cost for an acceptable threshold level of success, etc.)**
- **Deduce engineering requirements**
- **Layout an event decision tree including advanced technology options, and associated probabilities and costs**
- **Show impacts of technology investment on success criteria and order choices**

Revolutionary Aerospace Concepts (RASC) Study

Revolutionary mission capabilities anticipated for projected Europa missions over the next 25 years

Mission Launch Date	**2010**	**2025**
Minimum Surface Time	**10 days**	**1 year**
Number of instruments	**10**	**Miniature Life Detection**
Surface Penetration	**Just under**	**~1km in ice surface ice to ocean depth**
Mission Goal	**Characterize shallow subsurface**	**Search for life within the ocean**

Beyond flybys, orbiters, selected landers, this mission moves into the detailed search for life!

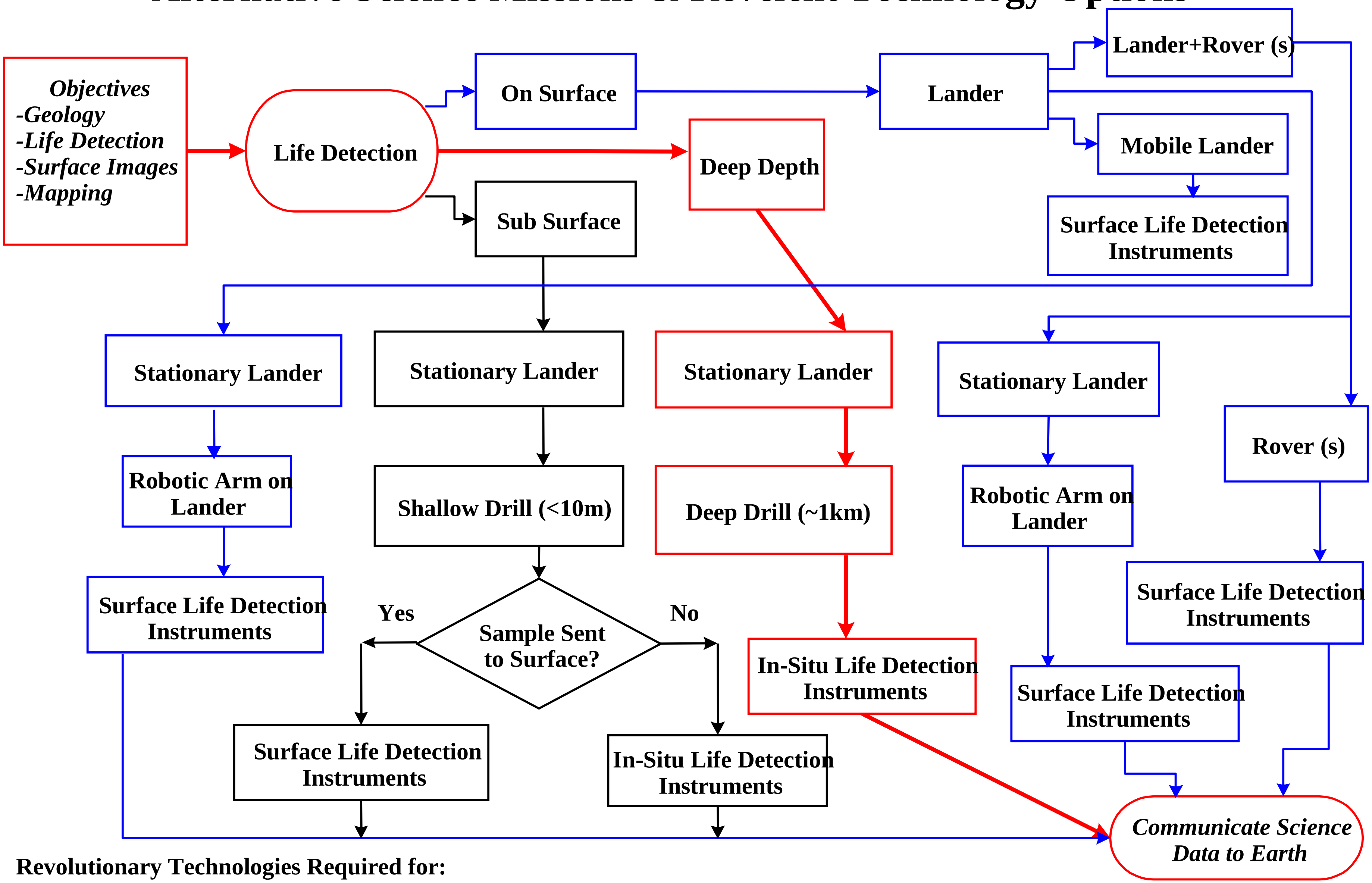
Performance Metrics

Technology	***Metric***
Entry Descent Landing	**<1 kg integrated; Precision Landing & Guidance @ ~1kmX5km**
ARPS- Stirling	**>8W/kg; >25% Efficient; >7 Year Life; > 100 W Size**
ARPS- Segmented Thermo-electrics	**>10W/kg; >15% Efficient**
Batteries	**> 200 W/kg**
Solar Electric Propulsion (SEP)	**PV >30% Efficient at 1 AU; >100 km/s; ISP >3800; <250 kg**
System on a Chip (SOC)- Communications	**> 180BPS/(W-gram); >4 Mrad;**
Life Detection	**Miniaturized with IR, UV, Raman, extinct & extantLife;<1kg; 5We**
Deep Ice Drilling- Cryobot	**<30 kg; <1 kWt;<50We;< 1m long; 1GHz Data Rate; >1km Deep**
Submarine	**<20 kg;<20 We;>2 year Life; Autonomous; Data Rate ~ 500 kbs**

Why are we using the Decision Tree For Analyses?

- **There are no single set of mathematical models available which describe the behavior of the complete system**
- **We can build decision trees and influence diagrams directly in an EXCEL spreadsheet, enter probabilities and payoffs directly in cells in a tree, and run a powerful decision analysis, including Monte Carlo simulation, on the resulting model to determine the best way to proceed with a technology R&D decision**
- **When we are faced with a set of alternative decisions, and to make decisions on funding R&D for new products, factoring in decisions at each stage of application and integration seems to make the best overall project decisions makes sense**

Alternative Science Missions & Revelent Technology Options



Revolutionary Technologies Required for:

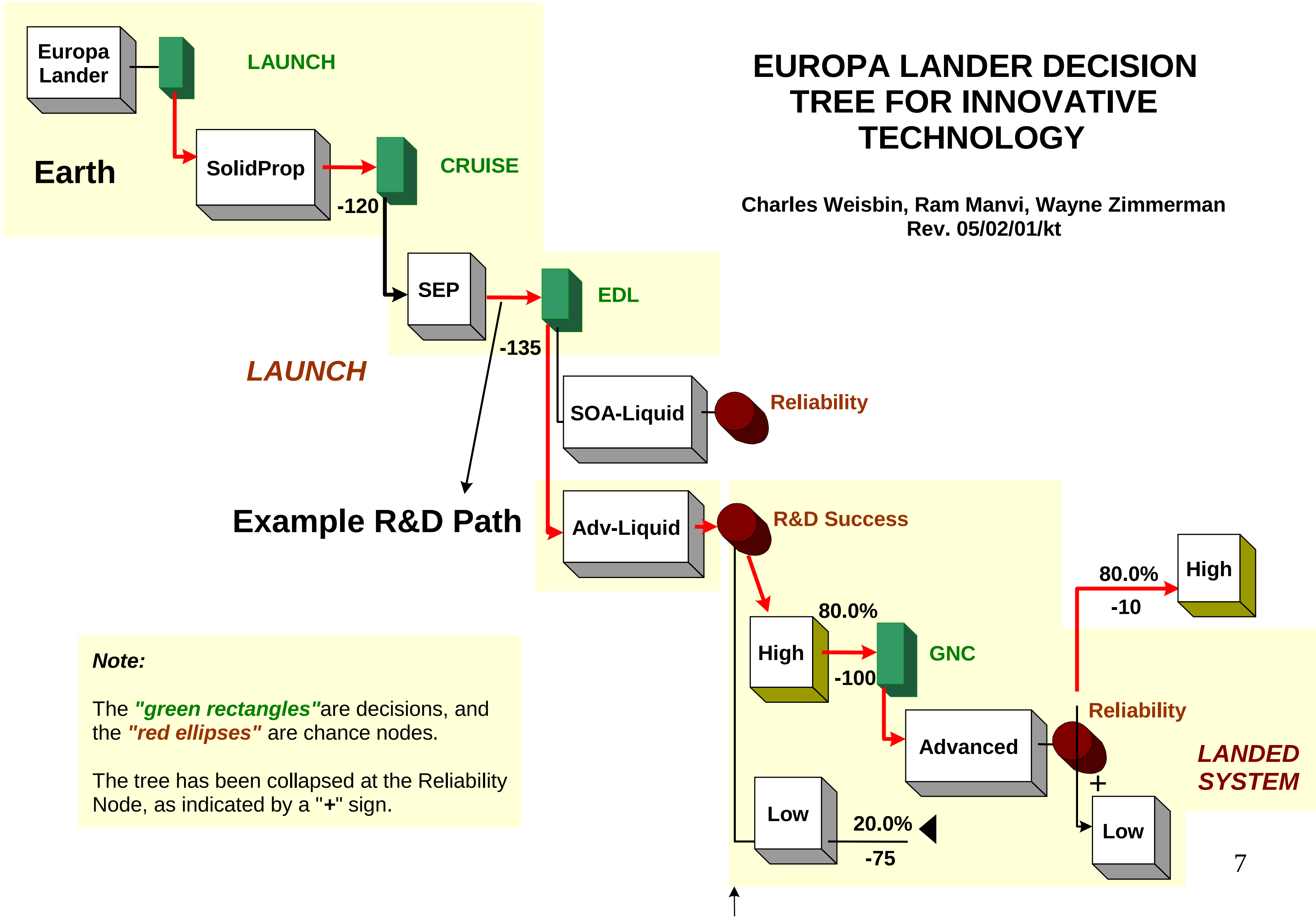
- **Reliable Advanced Power Systems (Nuclear, Solar, Solar+Secondary Batteries, Primary Batteries)**
- **Advanced Communications (Down-link & Up-link from & to SRO > 2kbps, and capable of 3>Gbytes data transfer**
- **Reliable drills, capable of drilling Europa Ice to depths of ~ 1km in 2< weeks**
- **Highly accurate Life Detection Instruments, miniaturized for in-situ applications at deep depths**

Orig/R. Manvi, 01/31/01
Rev/K. Taylor, 05/2/01

Europa Lander Decision Tree: Launch to EDL Phases

EUROPA LANDER DECISION TREE FOR INNOVATIVE TECHNOLOGY

Charles Weisbin, Ram Manvi, Wayne Zimmerman
Rev. 05/02/01/kt

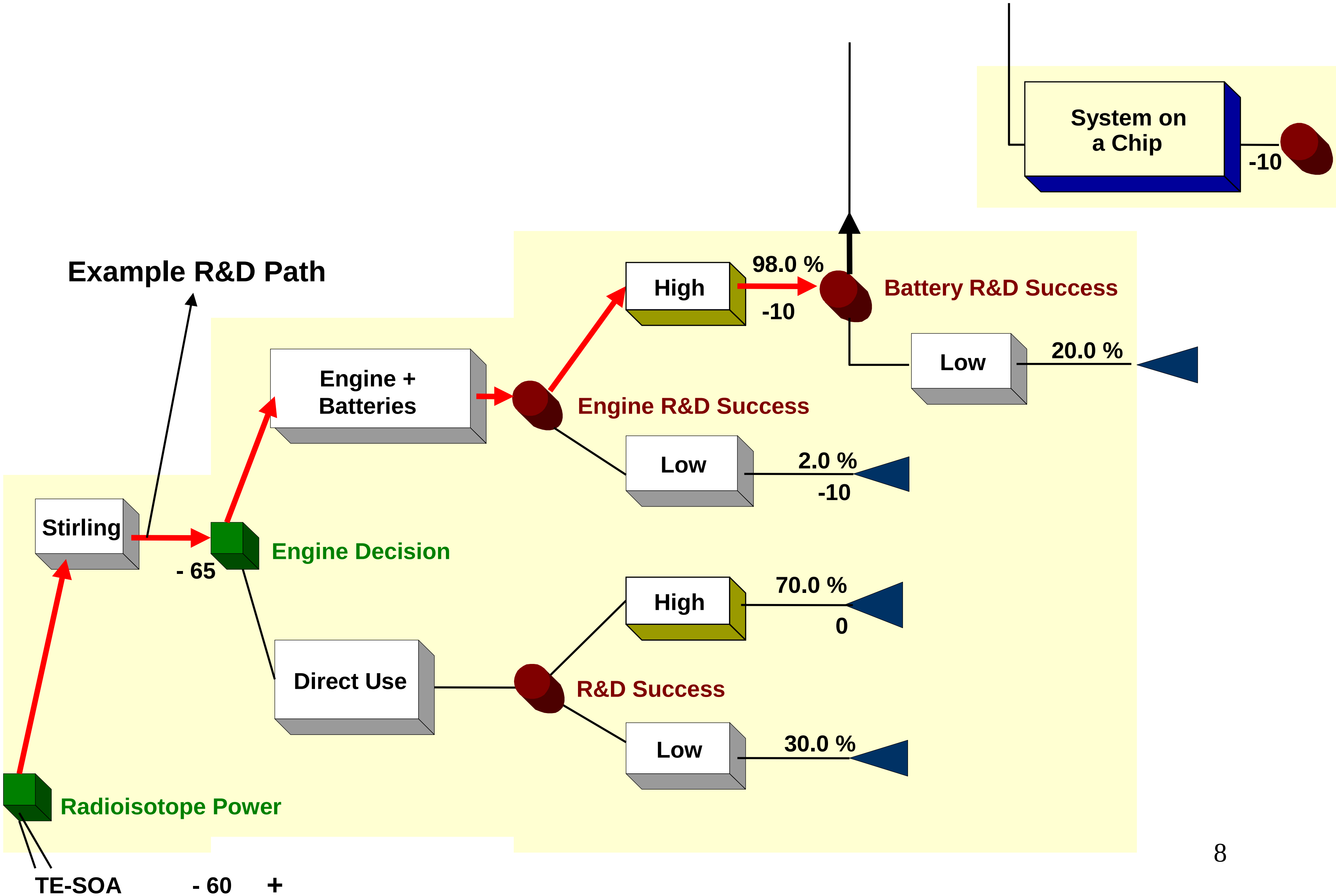


Note:

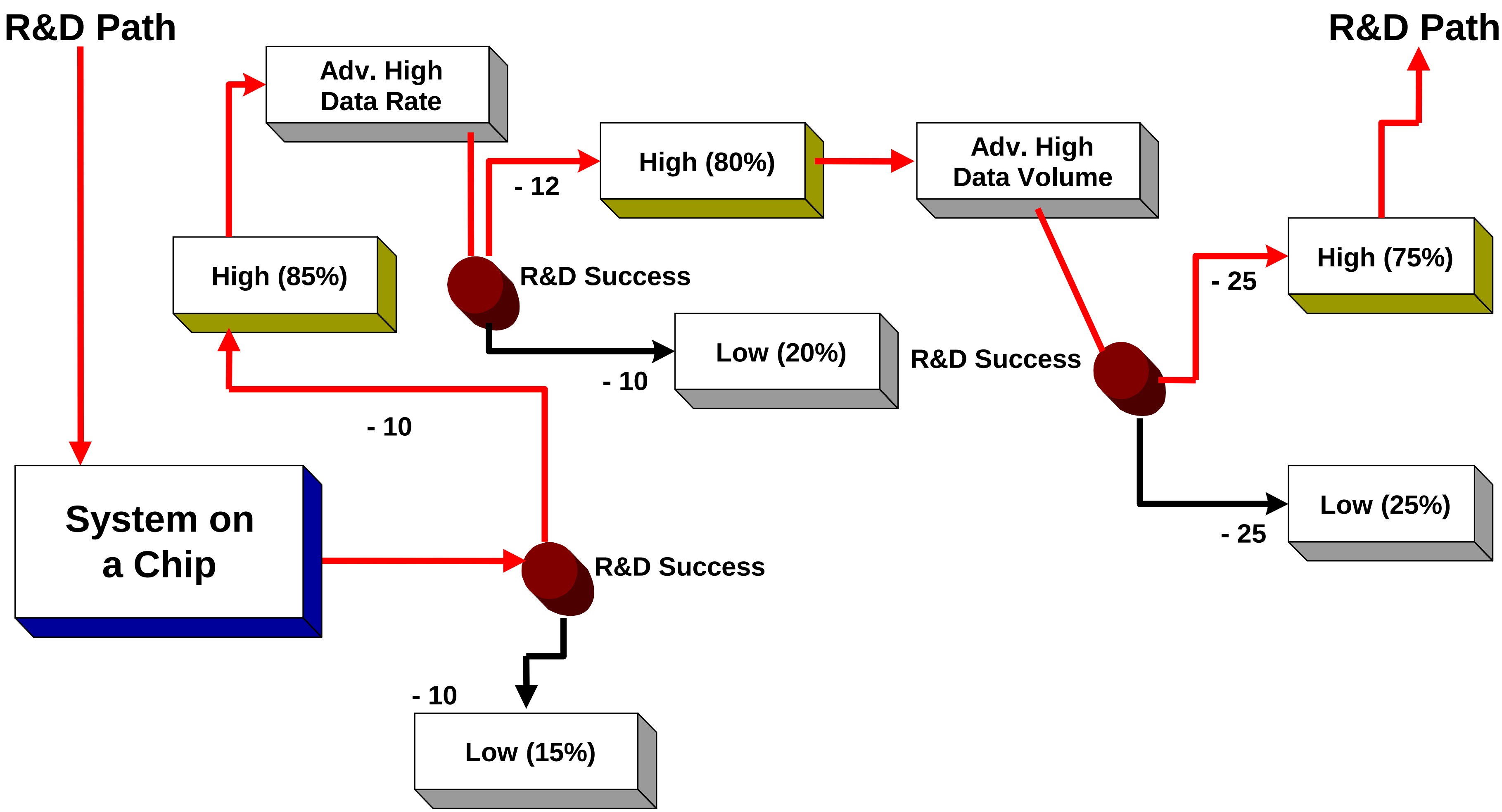
The ***"green rectangles"*** are decisions, and the ***"red ellipses"*** are chance nodes.

The tree has been collapsed at the Reliability Node, as indicated by a "**+**" sign.

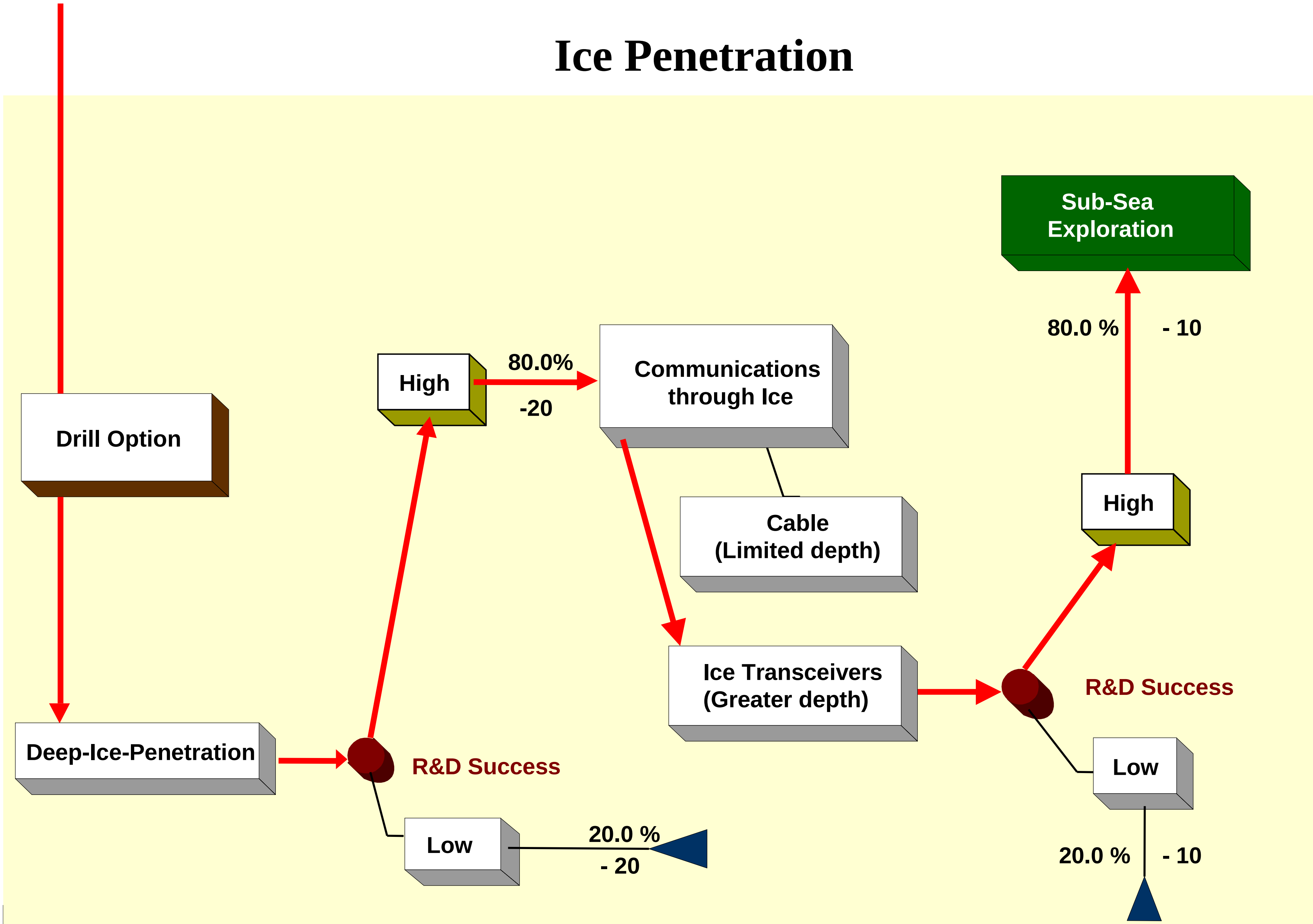
Europa Lander: Landed Phase Power Options



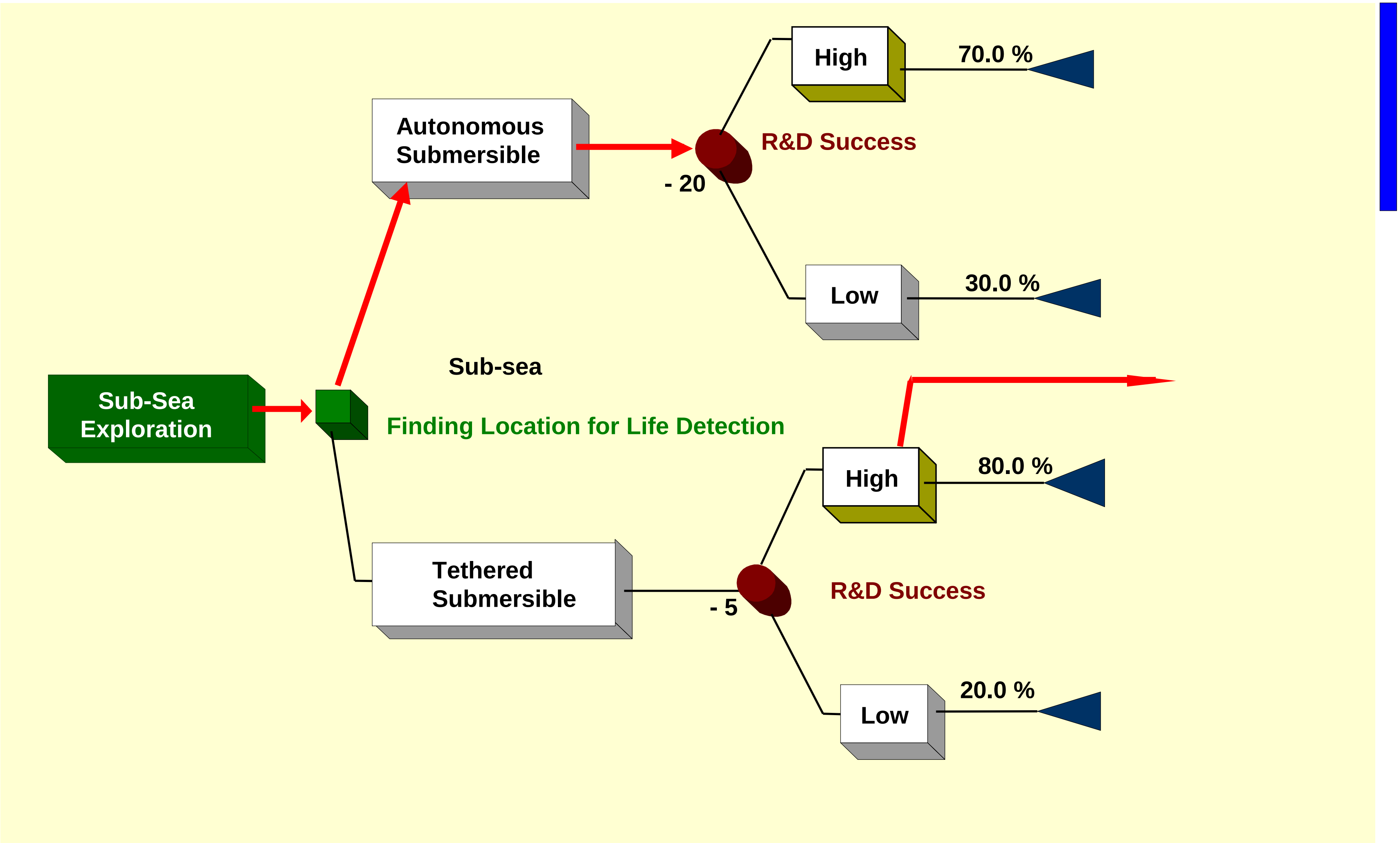
Communications: Lander/Orbiter/Earth



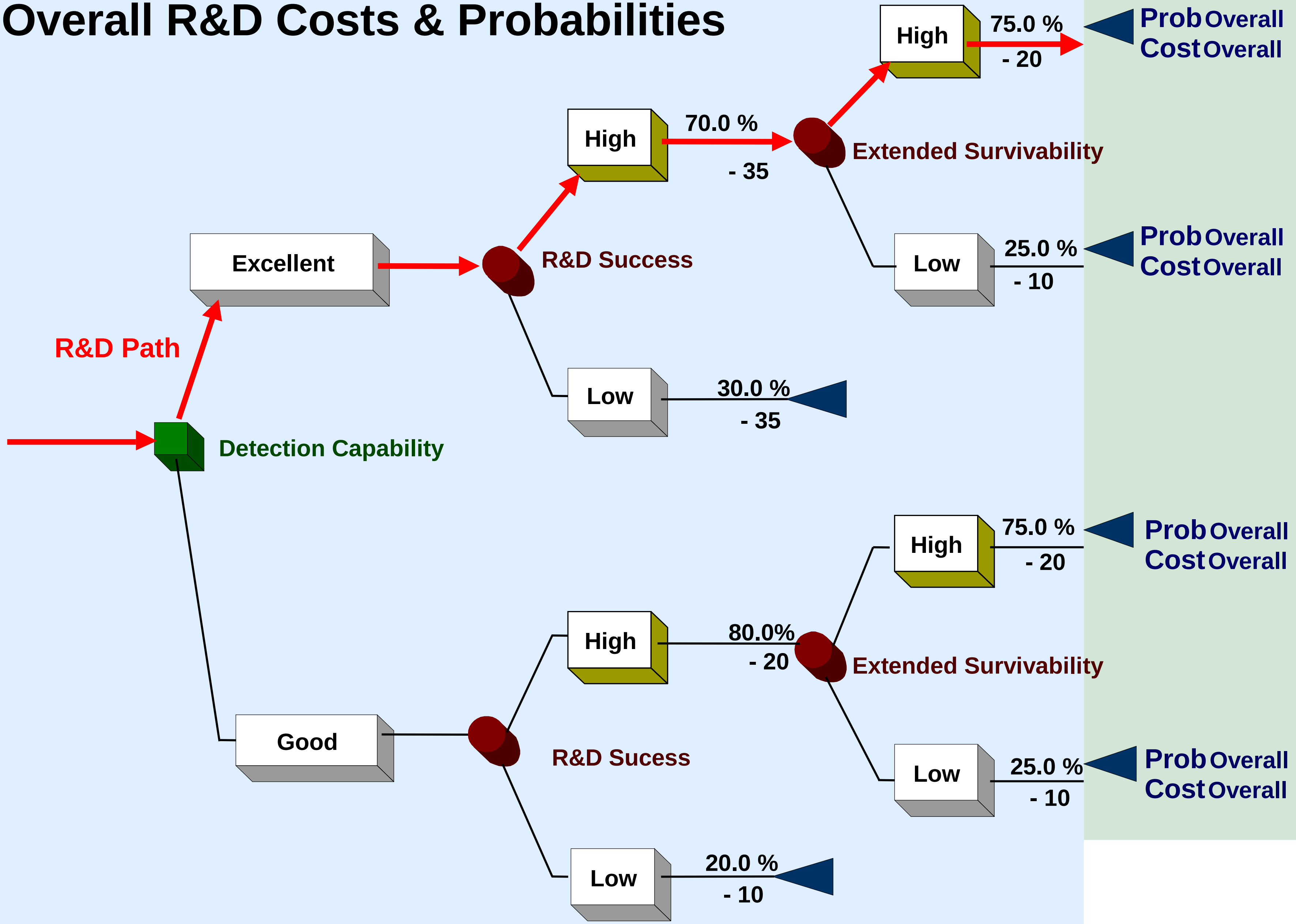
Ice Penetration



Sub-Sea Exploration



Overall R&D Costs & Probabilities



Europa Lander Decision Tree - Output End

The triangles are branch outputs

Metric Formulation for Technology Prioritization

Consider two links (formulation extensible to any number of links)

$p = p_1 * p_2$ **system probability**

$c = c_1 + c_2$ **system cost**

where $c_1 = f_1 * c$; $c_2 = (1-f_1) * c = f_2 * c$

differentiating:

$$dp = p_1 * dp_2 + p_2 * dp_1$$

$$dc = dc_1 + dc_2$$

Metric Formulation for Technology Prioritization (continued)

Solving for dp / dc we get:

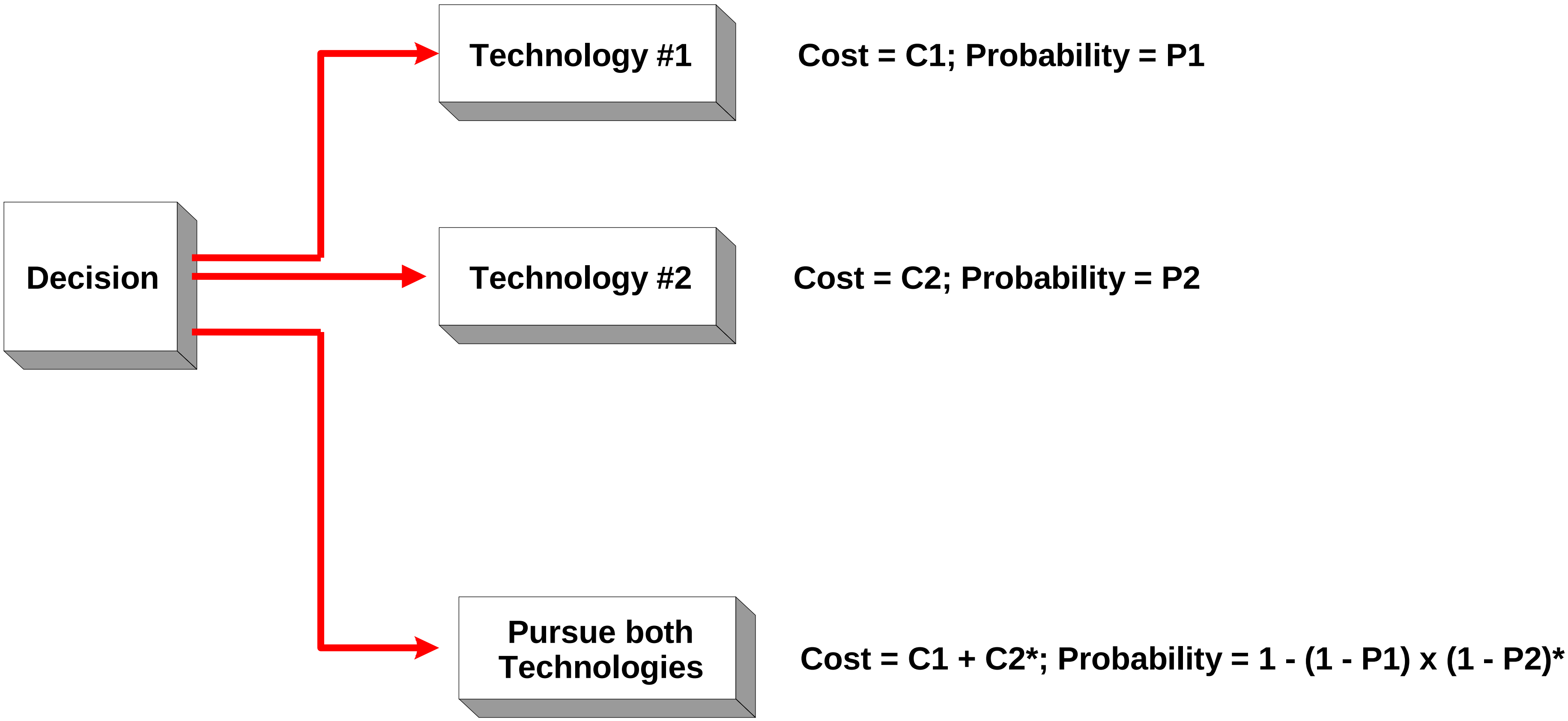
$$\frac{dp}{dc} = \left(\frac{dp_1}{dc_1} * f_1 * \frac{p}{p_1} + \frac{dp_2}{dc_2} * f_2 \right) * \frac{p}{p_2}$$

so to maximize the overall $\frac{dp}{dc}$

maximize each term; so

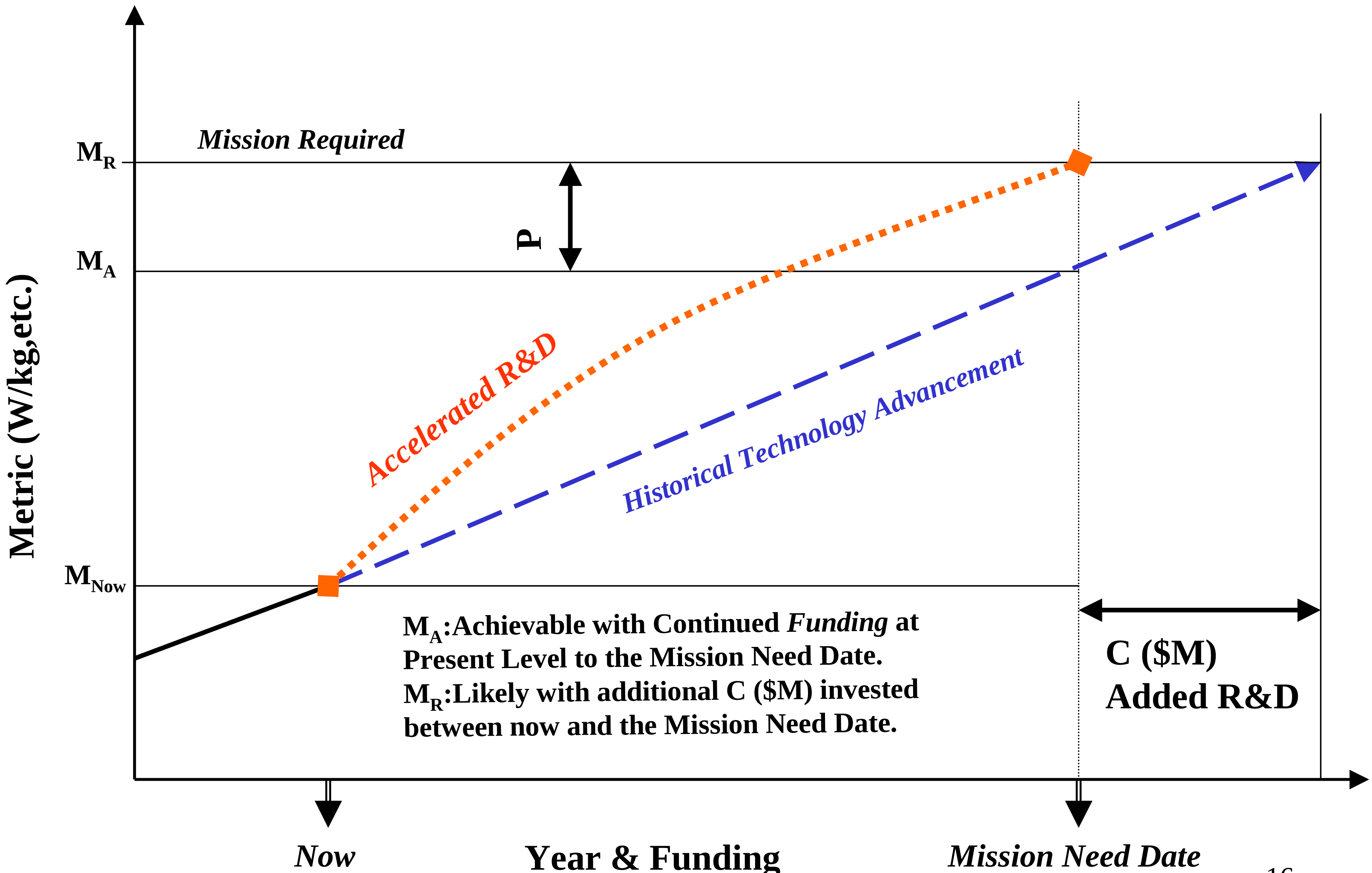
pick highest $\frac{dp_i}{dc_i} * \frac{p}{p_i}$ **, and rank order**

Redundant Technology Paths: How Handled?



Inputs in the Europa Lander Decision Tree, for redundant path

Approach to get δProbability/δCost



Ram Manvi, 02/10/01

Technology Feedback Influence

Technology Inter-Relationships Matrix

	SEP	Advanced Liquid Propulsion	Stirling	Advanced Batteries	SOAC	Commun-ications	Multi-functional Structures	Autonomous Control	Life Detection
SEP	—	↓ Mass/vol. Required	↑↑ Reliability ↑↑ Life ↑↑ Power	↑↑ Rqmt. for long life ↑↑ Energy Storage	↑ Power/ Fault Mgmt. Capability	—	↑ Low Mass/ Ablation Resistant Composites	↑ Intelligent Control s/w	—
Advanced Liquid Propulsion	↓ I_{sp} ↓ Vol/mass	—	—	—	↑ Propulsion/ Fault Mgmt. Capability	—	↑ High Temp./ Low Mass Composites ↑ Strength	↑ Fluid Control Capability	↑ Effluent Contamination Control
Stirling	↓ PV Electric Power	—	—	↓ Energy Storage Rqmt. ↓ Life Rqmt.	↑ Power Mgmt. Capability	↑ Deep Space Bandwidth	↑ High-temp. Materials	↑ Smart Power Mgmt.	—
Advanced Batteries	—	—	↑ Hybrid Compact Energy Storage	—	↑ Power Mgmt. Capability	↑ Short-range Transmit Power	—	↑ Smart Power Mgmt.	↓ Effluents/ Contamination
SOAC	—	—	↓ Power Supply Rqmt.	↓ Power Supply Rqmt.	—	↑ Comm. Reliability	—	↑ Intelligent Control s/w	↑ Detection Capability
Communications		—	↑ Power/ Reliability	↑↑ Rqmt for long life ↑↑ Energy Storage and Temp. Range	↑ Pointing Control/ Data Mgmt./ Fault Recovery	—	↑ Antenna Composite Materials ↓ Antenna Size/ Mass	↑ Smart Pointing/ Control s/w	—
Multi-functional Structures	—	—	—	—	↑ Embedded Smart Reconfig.	—	—	↑ Intelligent Reconfig. Control s/w	↑ Sample Acquisition Capability
Autonomous Control	↑ Efficiency	↑ Efficiency	↑ Reliability ↑ Efficiency	↑ Power Mgmt.	↑ In situ Intelligence	↑ Comm. Reliability	↑ Smart Reconfig. Control	—	↑ In situ Detection Capability
Life Detection	—	↑ Need for Clean Propellants	—	↑↑ Energy Storage for Long Duration	↑ Reliablity/ #Operations on Chip	↑ Data Volumn/Rate	↑↑ Micro Sampling/ Handling	↑↑ Func./ Intelligence	—

Key: (green) **= Technology** (blue) **= Technology Feedback Effect**

↑ Increase in performance will be required or potentially achievable

↑↑ Significant increase in performance required

↓ Decrease in performance required or performance can be relaxed

Example Evaluation

ALL OF THE INPUT DATA NEED TO BE REVIEWED AND AGREED UPON BY DOMAIN EXPERTS BEFORE THESE RESULTS ARE FINALIZED!!! NOT FOR FURTHER RELEASE

Logic Metric (X10^4)	Advanced Technology Item	Estimated R&D Cost (M$)	Cumulative R&D Cost (M$)
6.19	Deep Ice Penetration	25	25
6.03	Excellent Life Detection	25	50
5.21	System on a Chip	12	62
4.88	Sub-sea Mobility	20	82
2.74	Extended Survivability	20	102
2.72	Multifunctional Structure	12	114
2.71	Autonomous Hardware	20	134
1.78	Stirling Engine	85	219
1.45	High Volume COMM(24/7)	120	339
1.36	High Data Rate COMM	30	369
1.11	Thermal Control	12	381
0.96	Batteries	15	396

Work in Progress

- Plausibility and verification of probabilities and costs
  - Heritage of existing numbers documented for review
- Estimated mission reliability
  - Single project vs. program of missions
  - Redundant paths
- Introduction of time dependence as part of metric

Suite of Projects vs. One Grand Mission

- **Multiple concatenated projects increase the likelihood of success, with results from one mission feeding the next, but..**
- **The projected cost of a program might be larger than one single grand mission**
- **Another consideration is the leverage of one technology development through multiple projects within a program or to multiple programs.**

Revolutionary Aerospace Systems Concepts (RASC) Study

- **Used as a target mission, determine if Jupiter's Moon, Europa, contains the basic elements found in upper ice and potential sub-surface liquids to constitute the evidence of biological life outside of Earth**
  - **Developed approach to model (in software) the potential Europa life search mission, including technology development alternatives and associated costs.**
  - **Provide an audit trail for technological probability and cost assignments that can be traced and revised/concurred through peer review consensus**
  - **Develop and demonstrate a quantitative approach to ranking the technology alternatives quantitatively providing auditable rationale for selection.**
- **Work in progress**
  - **Gaining advocacy for the approach within the NASA enterprises.**
  - **Demonstrating the process for achieving consensus on investment strategy based on quantified models, data, and sensitivity analysis**